63-3-5

AFCRL-63-453

OPTIMUM DESIGN OF CYLINDRICAL ELECTRON BOMBARDMENT HEATERS

J.M. Houston, T.A. Howlett, and H.F. Webster

General Electric Company
Research Laboratory
Schenectady, New York

Contract No. AF19(604)-8424

Project No. 8659

Task No. 865902

Scientific Report No. 4

May 1963

Prepared

for

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
BEDFORD, MASSACHUSETTS

Requests for additional copies by Agencies of the Department of Defense, their contractors, and other government agencies should be directed to the:

DEFENSE DOCUMENTATION CENTER
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA

All other persons and organizations should apply to the:

U.S. DEPARTMENT OF COMMERCE
OFFICE OF TECHNICAL SERVICES
WASHINGTON 25, D.C.

ABSTRACT

It is shown that an optimum geometry exists for a cylindrical electron bombardment heater in which maximum thermal flux is to be delivered with stable operation and long life of the bombardment heater coil. The procedure for finding the stable operating condition is illustrated, and the optimum heater size is evaluated.

Manuscript received May 8, 1963.

OPTIMUM DESIGN OF CYLINDRICAL ELECTRON BOMBARDMENT HEATERS

J.M. Houston, T.A. Howlett, and H.F. Webster

Electron bombardment heaters often find application in heating electrodes to high temperatures when other methods such as radiative and conducting heating fail to transfer enough energy between a heater coil and the electrode to be heated. This poor heat transfer may result in a large temperature difference between the coil and the electrode, with the result that when the coil has been heated to its maximum safe temperature the electrode is still cooler than it needs to run. A current flow of electrons "I" from the coil accelerated by a voltage "V" will deliver I x V watts to the electrode in addition to the power delivered by radiation, with the result that the electrode can be treated hotter than the coil by this method.

This electron bombardment heating method has been used to heat the cathodes of thermionic converters because such cathodes require relatively high heat fluxes. Both parallel plane and cylindrical geometries have been used for this application, but this report will deal only with the cylindrical geometry in which the heater coil is a cylinder inside a larger cylindrical electrode. The question arises as to how much power can be delivered to the bombardment electrode by various geometries, coil temperatures, and accelerating voltages. This report will give an equation for this power and show that there is an optimum ratio of the radii of coil and electrode to yield the maximum power.

Before giving this result, however, it is necessary to consider the problem of the runaway heating of the coil, since this determines the operating point of the bombardment heating. This runaway problem is particularly severe in the cylindrical geometry because of the close coupling of the temperature of the outer electrode and the coil which is almost completely enclosed in the electrode. Figure 1 shows the construction of such a coil and electrode, which has been tested, and Fig. 2 shows the current voltage characteristic of this diode. If the heater current in the helix is set at an initial value with the bombardment voltage applied to the tantalum tube set to zero, then all the heat to the Ta tube is carried by radiation. As the bombardment voltage is raised, however, electron current is drawn from the helix to the Ta tube and additional heating results. The current-voltage characteristic follows one of the curves on Fig. 2 as this is done. Four curves are drawn for initial heater current values of 11, 11.5, 12, and 12.5 amp. As the Ta tube heats, some heat is carried back to the helix by radiation and more thermionic emission is available from the helix and the run-away effect results which can be seen in the curves for 11 and 11.5 amp. All of these curves approach a limiting line and this, of course, is the space-charge-limited emission line. When 12.5 amp of heater current are used, the emission is space-charge limited for almost all values of the bombardment voltage and this condition can be used if the runaway effect is to be avoided.

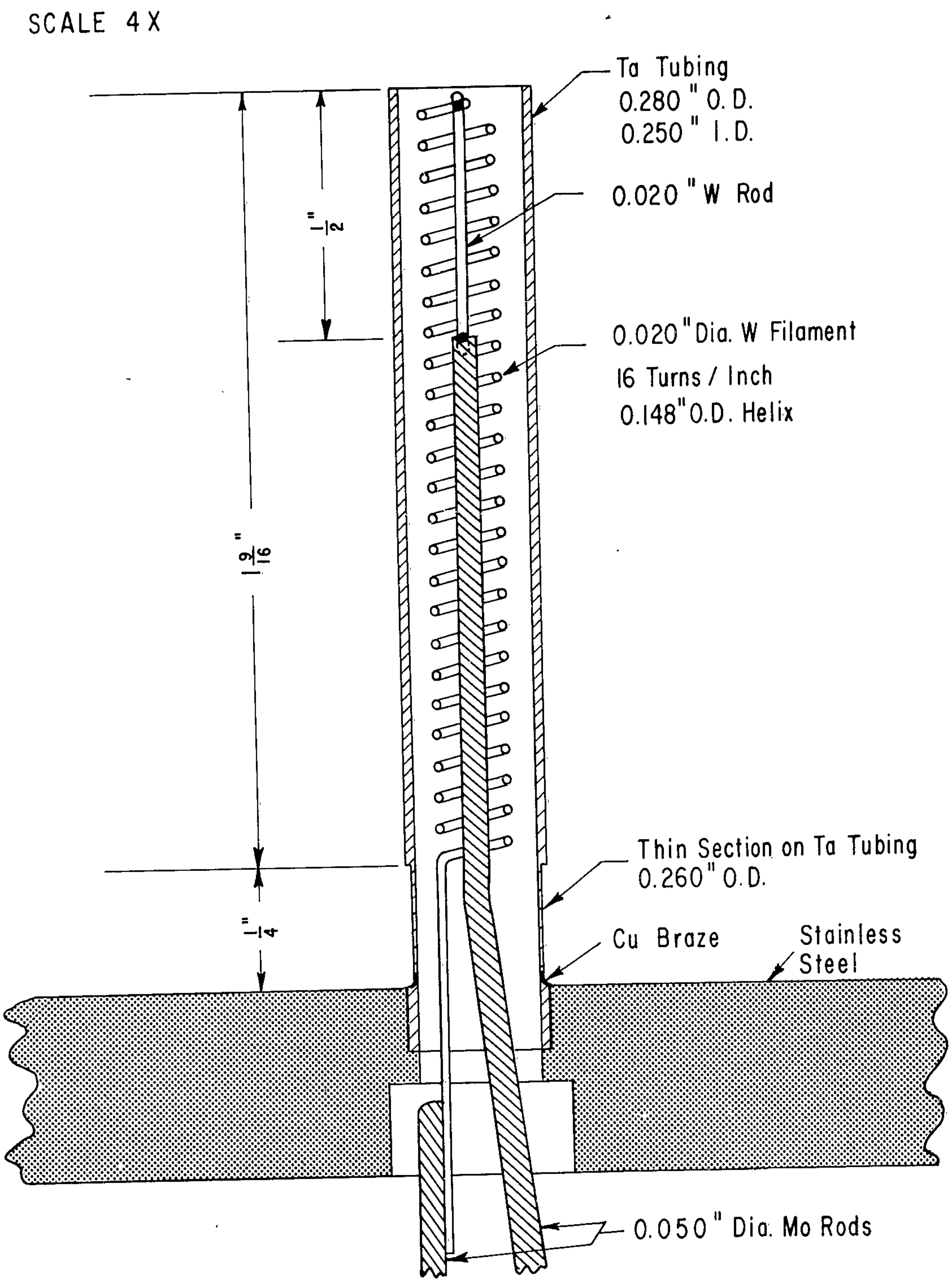

Fig. 1 Construction of electron bombardment heater coil.

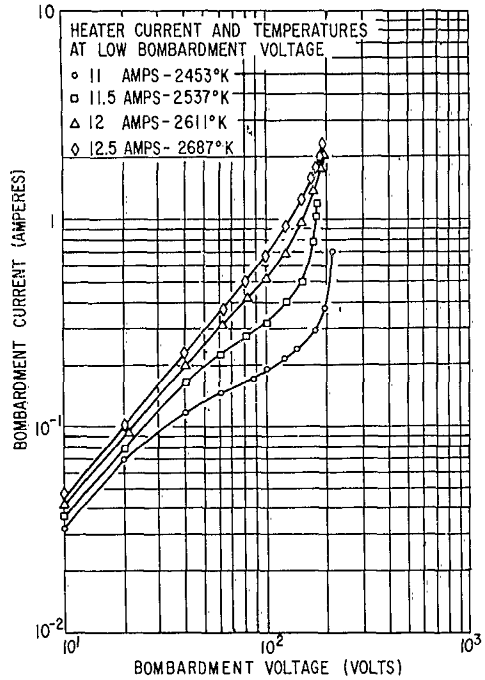

Fig. 2 Typical current-voltage characteristics for bombardment diode.

When these curves were measured for the four initial values of heater current, this current value was not kept constant throughout the run. Instead, the power supply voltage remained constant and the heater current decreased as the helix warmed up and its resistance increased. Similarly, the heater temperatures given for the four curves are the initial values and this temperature rose as the bombardment voltage increased.

To avoid the runaway effect, it is clear that the heater should be run hot enough to provide the space-charge-limited current but no hotter because, of course, this would provide no more current but would decrease the life of the heater.

The last part of this report will deal with the power that can be delivered to the anode of a cylindrical electron bombardment diode when it is operated in the space-charge-limited condition. It will be assumed that the diode is of length ℓ with the cathode a solid cylinder of radius r_c and the anode of radius R, where $R > r_c$. The space-charge-limited current flow from cathode to anode has been calculated by Langmuir and Blodgett [Phys. Rev., 22, 347 (1923)]

$$J_s = \frac{4\epsilon_0}{9} \sqrt{\frac{2e}{m}} \frac{V^{3/2}}{r_c R \beta^2} \quad \text{amp/unit cathode area.} \qquad (1)$$

V is the cathode-anode voltage and β is a function of r_c/R tabulated by Langmuir and Blodgett. J_s is in amp/cm^2, V is in volts, and r_c and R are in cm.

If J is the emission density from the cathode which is the maximum that can be obtained at the highest safe operating temperature, then the maximum total power which can be delivered to the anode by electron bombardment is

$$P = JV \; 2\pi \, r_c \ell \qquad (2)$$

where V is the voltage to obtain a space-charge-limited current density J as given by Eq. (1). By substituting V from Eq. (1) in Eq. (2), we obtain

$$P = \frac{2\pi \ell}{K^{2/3}} R^{7/3} J^{5/3} \left[\left(\frac{r_c}{R}\right)^{5/3} \beta^{4/3} \right] = \frac{2\pi \ell}{K^{2/3}} R^{7/3} J^{5/3} F,$$

where

$$K = \frac{4\epsilon_0}{9} \sqrt{\frac{2e}{m}} = 2.336 \times 10^{-6} \quad .$$

For a given maximum current density J, the anode radius R, and diode length ℓ, the maximum power will be delivered when the quantity in the square brackets, F, is maximized. This will then determine the optimum ratio of r_c to R. Table I shows the quantity F as a function of the ratio r_c/R and this has been plotted in Fig. 3. It will be seen that maximum power is delivered to the anode when the cathode has approximately half the radius of the anode (i.e., $r_c/R = 0.55$).

TABLE I

F as a Function of the Ratio of Cathode to Anode Radii

$\frac{r_c}{R}$	$\left(\frac{r_c}{R}\right)^{5/3} \beta^{4/3}$	$\frac{r_c}{R}$	$\left(\frac{r_c}{R}\right)^{5/3} \beta^{4/3}$
0.10	0.0213	0.556	0.1362
.20	.0574	.589	.1345
.25	.0756	.625	.1305
.33	.1032	.666	.1235
.345	.1065	.715	.1119
.3575	.1099	.770	.0946
.3705	.1132	.835	.0683
.385	.1168	.870	.0535
.40	.1201	.91	.0356
.417	.1237	.927	.0277
.435	.1268	.944	.0199
.455	.1300	.962	.0122
.476	.1326	.98	.0052
.50	.1344	.99	.0021
.526	.1356	1.00	0

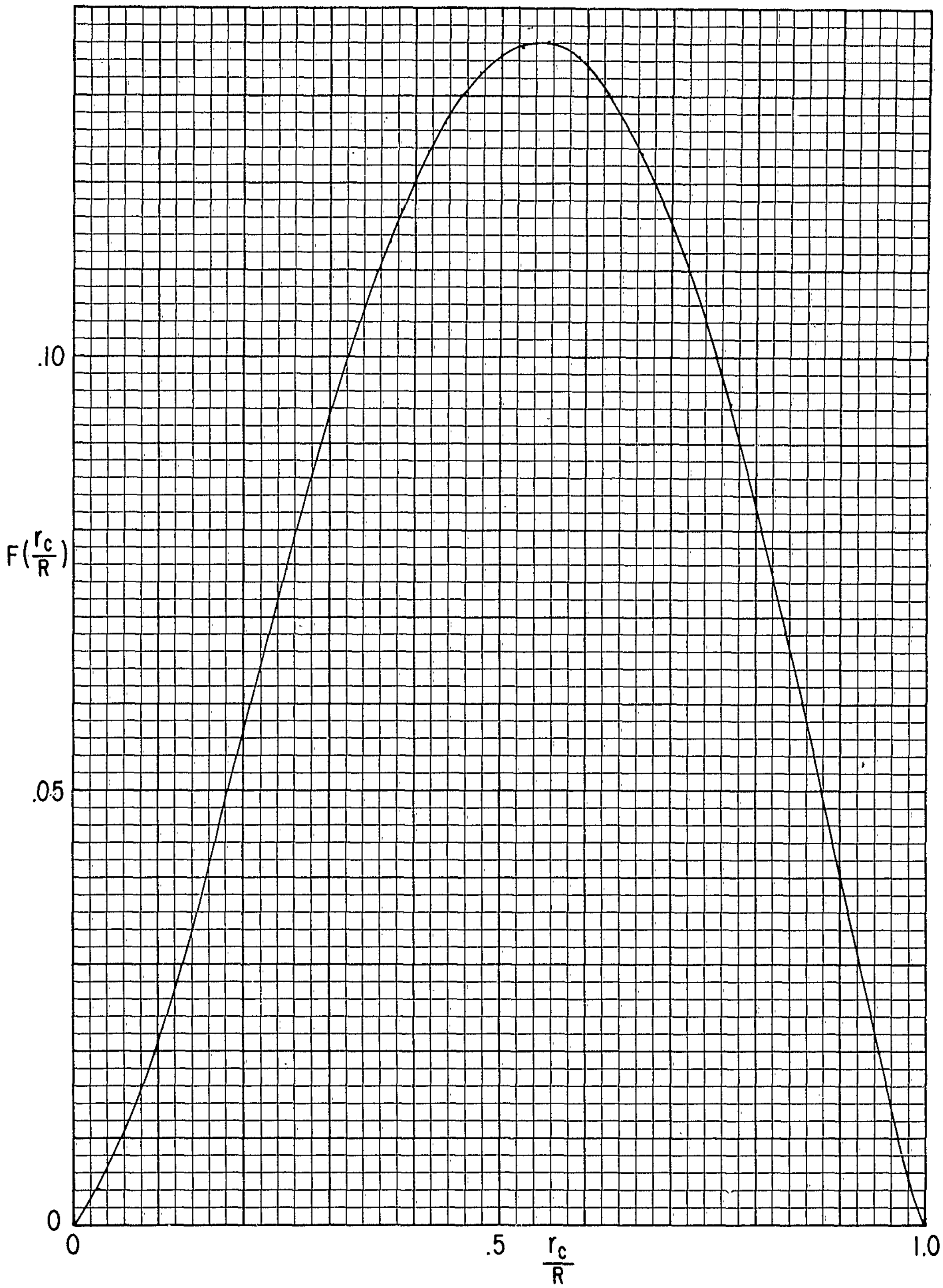

Fig. 3 Plot of F as a function of the ratio of cathode to anode radii.

Physically, the reason for this maximum can be seen from the following argument. As the cathode radius approaches zero, its area and the total current delivered will also approach zero. If the cathode radius approaches the anode radius, however, the current will be large but the highest voltage that can be used and still have space-charge-limited current will approach zero. The maximum lies between these two limits.

Contract No. AF-19(604)-8424
May 1963

DISTRIBUTION LIST

Code	Organization	No. of Copies
AF-2	A.U. (Library) Maxwell AFB, Alabama	1
AF-12	AWS (AWSSS/TIPD) Scott AFB, Illinois	1
AF-22	AFCRL, OAR (CRXR, Mr. John Marple) L.G. Hanscom Field Bedford, Massachusetts (U)	1
AF-23	AFCRL, OAR (CRXRA) Stop 39 L.G. Hanscom Field Bedford, Massachusetts	Please ship under separate cover as they must be sent to our Documents Unit. (20 cpys).
AF-26	AFCRL, OAR (CRZH, C.N. Touart) L.G. Hanscom Field Bedford, Massachusetts	1
AF-28	ESD (ESRDG) L.G. Hanscom Field Bedford, Massachusetts	1
AF-33	ACIC (ACDEL-7) Second and Arsenal St. Louis 18, Missouri (U)	1
AF-35	NAFEC Library Branch, Bldg. 3 Atlantic City, New Jersey ATTN: RD-702	1
AF-40	ASD (ASAPRD-Dist) Wright-Patterson AFB, Ohio	1
AF-43	Institute of Technology Library MCLI-LIB., Bldg. 125, Area B Wright-Patterson AFB, Ohio	1
AF-48	Hq. USAF (AFCSA, Secretary) Washington 25, D.C.	1

Code	Organization	No. of Copies
AF-49	AFOSR (SRGL) Washington 25, D. C.	1
AF-51	Hq. USAF (AFRDR) Washington 25, D. C.	1
AF-58	ARL (ARA-2) Library AFL 2292, Building 450 Wright-Patterson AFB, Ohio	1
AF-62	Hq. AFCRL, OAR (CRZWD, Irving I. Gringorton) L. G. Hanscom Field Bedford, Massachusetts	1
G-66	Scientific and Technical Information Facility ATTN: NASA Representative (S-AK-DL) P. O. Box 5700 Bethesda, Maryland	1
G-67	Office of Scientific Intelligence Central Intelligence Agency 2430 E Street, N. W. Washington 25, D. C.	1
AR-7	Commanding Officer U. S. Army Research and Development Laboratory Fort Monmouth, New Jersey	1
AR-13	Technical Documents Center Evans Signal Labs. Belmar, New Jersey	1
AR-15	Army Research Office Environmental Research Division 3045 Columbia Pike Arlington 4, Virginia	1
AR-16	Office of the Chief of Research and Dev. Department of the Army The Pentagon Washington 25, D. C.	1

Code	Organization	No. of Copies
F-7	Technical Information Office European Office, Aerospace Research Shell Building, 47 Cantersteen Brussels, Belgium (U)	1
F-50	Defense Research Member Canadian Joint Staff 2450 Massachusetts Ave., N.W. Washington 8, D.C. (U)	2
G-5	Librarian Boulder Laboratories National Bureau of Standards Boulder, Colorado (U)	1
G-21	ASTIA (TIPAA) Arlington Hall Station Arlington 12, Virginia	20
G-34	Documents Expediting Project (Unit X) Library of Congress Washington 25, D.C. (U)	1
G-40	Library National Bureau of Standards Washington 25, D.C. (U)	1
G-41	National Research Council 2101 Constitution Avenue Washington 25, D.C. (U)	1
G-47	Office of Secretary of (DDR and E, Tech. Library) Washington 25, D.C. (U)	1
G-49	Superintendent of Documents Government Printing Office Washington 25, D.C. (U)	1
G-51	Science Advisor Department of State Washington 25, D.C. (U)	1

Code	Organization	No. of Copies
G-52	Director of Meteorological Research U.S. Weather Bureau Washington 25, D.C.	1
G-53	Library U.S. Weather Bureau Washington 25, D.C.	1
I-7	Director, USAF Project RAND The Rand Corporation 1700 Main Street Santa Monica, California Thru A.F. Liaison Office	1
I-8	Dr. William W. Kellogg Rand Corporation 1700 Main Street Santa Monica, California (U)	1
I-40	Institute of Aerospace Sciences, Inc. 2 East 64th Street New York 21, New York (U)	1
I-46	Mr. Malcolm Rigby American Meteorological Society P.O. Box 1736 Washington 13, D.C. (U)	1
N-6	Technical Reports Librarian U.S. Naval Postgraduate School Monterey, California (U)	1
N-16	OAR (Geophysics Code N-416) Office of Naval Research Washington 25, D.C.	1
N-19	Director U.S. Naval Research Laboratory Code 2027 Washington 25, D.C.	1

Code	Organization	No. of Copies
U-1	Library Geophysical Institute University of Alaska P.O. Box 938 College, Alaska (U)	1
U-10	Professor Clarence Palmer Institute of Geophysics University of California Los Angeles 24, California (U)	1
U-13	Dr. Joseph Kaplan Department of Physics University of California Los Angeles, California (U)	1
U-21	Dr. A.M. Peterson Stanford University Stanford, California (U)	1
U-40	Dr. David Fultz Department of Meteorology University of Chicago Chicago, Illinois (U)	1
U-56	Prof. Fred L. Whipple Harvard College Observatory 60 Garden Street Cambridge 38, Massachusetts (U)	1

Remaining copies to:
Hq. AFCRL, OAR (CRFE, Dr. Norman Rosenberg)
L. G. Hanscom Field
Bedford, Massachusetts

General Electric Research Laboratory, Schenectady, N. Y. OPTIMUM DESIGN OF CYLINDRICAL ELECTRON BOMBARDMENT HEATERS, by J.M. Houston, T.A. Howlett, and H.F. Webster. May 1963. 6p. incl. illus. (Proj. 8659; Task 865902) (AFCRL-63-453) Scientific Report [Contract AF19(604)-8424]

Unclassified report

It is shown that an optimum geometry exists for a cylindrical electron bombardment heater in which maximum thermal flux is

(over)

UNCLASSIFIED

UNCLASSIFIED

to be delivered with stable operation and long life of the bombardment heater coil. The procedure for finding the stable operating condition is illustrated, and the optimum heater size is evaluated.

UNCLASSIFIED

UNCLASSIFIED

General Electric Research Laboratory Schenectady, N. Y. OPTIMUM DESIGN OF CYLINDRICAL ELECTRON BOMBARDMENT HEATERS, by J.M. Houston, T.A. Howlett, and H.F. Webster. May 1963 6p. incl. illus. (Proj. 8659; Task 865902) (AFCRL-63-453) Scientific Report [Contract AF19(604)-8424]

Unclassified report

It is shown that an optimum geometry exists for a cylindrical electron bombardment heater in which maximum thermal flux is

(over)

UNCLASSIFIED

UNCLASSIFIED

to be delivered with stable operation and long life of the bombardment heater coil. The procedure for finding the stable operating condition is illustrated, and the optimum heater size is evaluated.

UNCLASSIFIED

UNCLASSIFIED